Toposequence in Gununo Area, Southern Ethiopia

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Abstract

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Six soil profiles of different landscapes, representing convex crest, top-slope, mid-slope and depression, were studied along a toposequence, to assess the influence of topography and management practice on soil characteristics in the Gununo area of S. Ethiopia. The soil profiles on the convex crest, at the low side of the terrace on mid-slope and depression had deep, dark surface layers as compared to the others, and the continuous deposition of soil material on the depression had led to lithological discontinuity. Clay migration and coatings were observed in the subsurface layers of the pedons, except in the pedon in the depression. Generally, the soil structure was angular to sub-angular blocky with varying grades. The dry consistency of the soils in the surface layers was by and large slightly hard, whereas the moist consistency was invariably friable. The wet consistency indicated various degrees of stickiness and plasticity. The soils were slightly to moderately acidic (pH <6.4), with CEC ranging from 21.3 to 44 $\text{cmol}_c\,\text{kg}^{-1}$ and high in exchangeable Mg on the surface layers. The organic C and total N were low to medium, although the C:N ratio was almost optimal. The available P of the surface layers was low to very low (2.2–4.6 mg kg^{-1}), except for the soils of the pedon on the convex crest, which had 7.8 mg P kg^{-1}, whereas exchangeable K contents were below the critical limit in some of the pedons. The results revealed that slope and management practices influenced soil properties, suggesting the need for development and/or adoption of appropriate management options for varying slope gradients.

Keywords: toposequence, pedon, slope position, soil characteristics

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Introduction

Agriculture, accounting for about 45% of GDP and 85% of total employment, is the dominant sector in the national economy of Ethiopia (CSA, 2010). This sector is, however, beset by several natural and anthropogenic factors that adversely affect its productivity (Ahmed, 2002; Woldeamlak, 2003). Increasing population pressure expanded farming from gently sloping surfaces in the highlands to steeper slopes and marginal lands (Azene, 1997; Demel, 2001) which in turn have brought disturbance to the ecosystems, particularly soils, that are the determinant factors of agricultural production and productivity. Assessment of soil quality with respect to landuse types and management practices is therefore crucial for sustainable agriculture.

All soils are naturally variable; their properties changing across the landscape and vertically down the soil profile (Brubaker *et al.*, 1993; Brady & Weil, 2002). Soils commonly occur in groups, each member of the group occupying a characteristic and different sequential topographical position from top to bottom of a slope, termed as *toposequence*. When the same sequence occurs as a mirror image on similar parent material, the two toposequences are called a *catena* (Buol *et al.*, 2003). The prevalence of differences in soil properties along a landscape affects not only patterns of plant production but also litter production and decomposition. Soil properties such as clay, sand and pH (Ovalles & Collins, 1986) and organic matter (Miller *et al.*, 1988; Pierson & Mulla, 1990; Bhatti *et al.*, 1991) correlate highly with landscape position. Soil properties can also vary with landuse and management systems. Land management and its various uses for crop production in mountain areas influence runoff and erosion, which in turn result in varying physicochemical properties of the soils under cultivation and grazing lands (Belayneh, 2009).

Gununo area, in Southern Nations', Nationalities' and Peoples' Regional State (SNNPRS) of Ethiopia, is densely populated (400–600 km^{-2}), with very small farm size (averaging 0.25 ha per farming family). Intensive cultivation in this area, with subsequent removal of plant residues, has resulted in severe degradation of soil fertility. Subdivision of the fields into several plots for various purposes (field crops and vegetable production, enset (*Ensete ventricosum*) and coffee (*Coffea arabica*) plantation, and for tethering animals) has led to different soil fertility gradients and has complicated management. The decline in soil fertility is exacerbated by soil erosion, which is aggravated by steep slopes, poor vegetation cover and continuous cropping. Thus, different points along the slope require different management practices. The present study was therefore carried out to assess the morphological, physical and chemical properties of the soils under different landuse systems along the toposequence, and to generate data for management options.

Materials and Methods

The study was conducted at Gununo, in Wolaita Zone of the SNNPRS of Ethiopia. The study site is situated 30 km W of Sodo town at 6º56´ N lat., 37º39´ E long., at altitudes between 1880 and 1960 m above sea level (m asl). The area receives a mean annual rainfall of 1350 mm and has a mean annual air temperature of 18.5 ºC. The main crops grown in the area are cereals such as *teff (Eragrostis tef),* maize *(Zea mays),* wheat *(Triticum aestivum*), barley *(Hordeum vulgare*); pulses such as faba bean (*Vicia faba),* field pea (*Pisum sativum*), haricot bean (*Phaseolus vulgaris*); and root and tuber crops such as potato (*Solanum tuberosum*), sweet potato *(Ipomea batatas)* and enset (*Ensete ventricosum*).

Six soil profile pits were excavated at different slope gradients on various positions of the landscape, representing convex crest, top-slope, mid-slope and depression. Pedon 1 was located on convex crest, 2 and 3 were on top-slope, 4 and 5 were on mid-slope, whereas Pedon 6 was in a depression. Pedons 1 and 6 were on grass cover; Pedons 2 and 3–5 were on maize and wheat fields, respectively. The soil profiles were described *in situ* following Guidelines for Soil Profile Description (FAO, 1990), and samples collected from identified genetic horizons. The samples were processed and analysed for physicochemical properties, following standard laboratory procedures.

Particle-size distribution was determined by the modified hydrometer sedimentation method, and soil pH in H_2O using a 1:2.5 soil to solution ratio (Van Reeuwijk, 1993). The organic carbon was analyzed by the wet combustion method of Walkley and Black (Van Ranst *et al.*, 1999), total nitrogen (N_{tot}) by the Kjeldahl wet digestion and distillation procedure (Bremner & Mulvaney, 1982), and available phosphorus by the 0.5*M* sodium bicarbonate extraction (pH 8.5) method (Olsen & Sommers, 1982). The CEC and exchangeable bases were determined by the 1*M*-ammonium acetate (pH 7) method (Van Reeu-wijk, 1993), and base saturation (BS) was computed.

Results and Discussion

Site characteristics

The site characteristics of the six pedons indicated differences in slope, permeability and extent of erosion (Table 1, overleaf). Pedons 2 and 3 were on slopes of 18% and 9%, respectively, whereas the remaining pedons were on gentle slopes (2–4%). The physiography ranged from convex plateau to undulating slope and depression, showing nil erosion in the depression (Pedon 6) to moderate erosion at the mid-slope position (Pedon 2 and 3), on a basaltic landform with well-drained soils, except in the depression (Pedon 6), which was of alluvial parent material and poorly drained.

Morphological features

The morphological descriptions of the pedons (Table 2 overleaf, opposite) showed that all the profiles had deep soils, while those on convex crest (Pedon 1) and depression (Pedon 6) had deeper and darker surface layers as compared to the others. These might be attributed to relatively low removal of surface soil by water erosion at the convex crest (plain with 2% slope), and continuous deposition of soil material in the depression, resulting in lithological discontinuity in the latter, as indicated by the abrupt change in textural class within the profile (Table 3). The greatest depth to the B horizon was, however, recorded on Pedon 5, situated on the lower side of the terrace, this indicates accumulation of materials originating in topographically higher pedons. Mulugeta Demis (2006) found a deeper A-horizon in pedons in lower slope positions, as compared to those on the upper and middle slopes. Mulugeta Demis explained that the greatest erodibility was associated with upper-slope positions, where soils tended to be shallow, coarse, poorly leached and low in organic matter, whereas low erodibility was found in lower-slope positions with deep, organic-rich and leached soils.

The soil colour of the surface layers varied from 2.5YR to 10YR, although the moist soil colour of the same layers invariably indi-

Table 1. *Site characteristics of the pedons*

Pedon	Geographical position		Altitude (m asl)	Physiography	Slope (%)	Permeability	Drainage	Erosion	Landuse	Parent material
	N Lat.	E Long.								
1	06°56.34´	37°39.80´	1960	Convex plateau	2	Moderately rapid	Well drained	Slight	Grassland	Basalt
2	06°56.32´	37°39.50´	1930	Undulating, upper slope	18	Moderately rapid	Well drained	Moderate	Cropped for maize	Basalt
3	06°56.29´	37°39.95´	1925	Undulating, upper slope	9	Moderately rapid	Well drained	Moderate	Cropped for wheat	Basalt
4	06°56.25´	37°39.54´	1920	Undulating, middle slope	3	Moderately rapid	Well drained	Slight	Cropped for wheat	Basalt
5	06°56.34´	37°39.60´	1910	Undulating, middle slope	4	Moderately rapid	Well drained	Slight	Cropped for wheat	Basalt
6	06°56.57´	37°39.29´	1880	Depression	2	Moderately slow	Poorly drained	Nil	Grassland	Alluvium

[1:] C = Clay; CL = Clay loam; SiL = Silt loam

cated a lower value, chroma or both (Table 2). The decrease in value and chroma could be attributed to the influence of soil moisture on the reflection of light and purity of the colour, respectively. Light absorption increases when the soil is wet, hence the soil colour value decreases. Similarly, purity of the spectral colour decreases with absorption of moisture by the soil, resulting in reduction of the chroma. The determination of soil colour revealed that all the soils were well drained, except Pedon 6, where mottles were prevalent throughout the profile, indicating imperfect drainage conditions due to repeated wetting and drying.

Except in Pedon 6, which consisted of contrasting materials deposited by water at different times, the field soil texture as estimated by the feel method below the surface layers invariably became finer (Table 2), owing to clay migration, which was confirmed by clay coatings observed in the subsurface layers of the pedons. The soil structure was generally angular to sub-angular blocky of various degrees, except in the surface layer of Pedon 4 and in the subsurface horizon of the depression Pedon, which had granular and single-grain structure, respectively. The size of the peds generally increased with depth due to an increase in clay content, as explained by Brady & Weil (2002). The dry consistency of the surface soil was by and large slightly hard, whereas the moist consistency was invariably friable, indicating a high rate of water absorption. The wet consistency revealed various grades of stickiness and plasticity.

Particle-size distribution

The textural class of the soils did not vary under different landuse systems, indicating that mineral particles in a soil are not readily subject to change by management practices (Prasad & Power, 1997). The texture of the subsurface horizons, except Pedon 6, became finer with depth, due to migration of clay from surface to lower horizons (Table 3). It was also evident in the progressive decrease in the silt:clay ratio with depth of pedons. The low silt-to-clay ratios in the subsoil layers also indicate that the soils are at an advanced stage of development (Abayneh, 2005), and confirm the existence of clay migration in the pedons.

Table 2. *Morphological description of the pedons*

P*	Depth (cm)	Horizon	Boundary[1]	Colour		Field textural class [2]	Structure [3]	Consistency [4]	Roots [5]	Special features, if any [6,7]
				Dry	Moist					
1.	0–50	A	C,S	10YR3/3	10YR 3/2	CL	WE,FI,SB	SHA,FR,SST,SPL	M,Fi	-
	50–113	B1	G,S	-	2.5YR 3/3	C	WE,FI,AB	FR,SST,SPL	M,Me	-
	113–220	B2	G,S	-	2.5YR 3/4	C	WE,ME,AB	FR,SST,SPL	F,Fi	F,F,SF,P[6]
	220–300*	B3	-	-	2.5YR 3/4	C	WE,ME,AB	FR,SST,SPL	-	F,F,SF,P[6]
2.	0–20	Ap	C,S	2.5 YR 3/4	2.5YR 2.5/4	CL	WE,FI,SB	HA,FR,SST,SPL	F,Me	-
	20–47	Bt1	G,S	-	2.5YR 2.5/3	CL	MO,ME,SB	FR,SST,SPL	F,Fi	F,F,C,P[6]
	47–86	Bt2	G,S	-	10R 3/3	C	MO,ME,AB	FR,SST,SPL	F,Me	F,F,C,P[6]
	86–200	Bt3	-	-	10R 3/4	C	WE,ME,AB	FR,SST,SPL	F,Me	C,F,C,P[6]
3.	0–25	Ap	C,S	5YR4/4	2.5YR 3/2	SiCL	WE,FI,SB	SHA,FR,SST,SPL	M,Fi	-
	25–63	Bt1	G,S	-	2.5YR 3/4	CL	MO,ME,AB	FR,SST,SPL	C,Me	-
	63–118	Bt2	G,S	-	2.5YR 3/3	C	MO,FI,SB	FR,SST,SPL	M,Fi	F,F,C,P[6]
	118–200*	Bt3	-	-	10YR 3/4	C	MO,ME,SB	FR,ST,PL	-	F,F,C,P[6]
4.	0–15	Ap	C,S	7.5YR 2.5/3	2.5YR 2.5/1	CL	WE,ME,GR	SHA,FR,SST,SPL	M,Me	-
	15–58	AB	C,S	-	10YR 2/1	C	WE,ME,SB	FR,ST,PL	M,Me	-
	58–100	Bt1	G,S	-	2.5YR 2/4	C	WE,ME,SB	FR,ST,PL	F,Fi	F,F,C,P[6]
	100–200*	Bt2	-	-	10YR 3/3	C	WE,ME,SB	FR,SST,SPL	V,Fi	F,F,C,P[6]
5.	0–20	Ap	C,S	5YR4/4	5YR 3/2	CL	WE,FI,AB	SHA,FR,SST,SPL	M,Fi	-
	20–52	A11	C,S	-	5YR 3/3	CL	WE,FI,AB	FR,SST,SPL	C,Fi	-
	52–70	A12	G,S	-	5 YR 2.5/2	C	WE,FI,AB	FR,SST,SPL	F,Fi	-
	70–105	AB	C,S	-	2.5YR 3/1	C	WE,ME,AB	FR,ST,PL	F,Fi	F,F,C,P[6]
	105–200*	B	-	-	2.5YR 3/4	C	WE,ME,AB	FR,ST,PL	-	F,F,C,P[6]
6.	0–40	A	G,S	7.5YR 4/4	2.5YR 2.5/3	C	WE,FI,AB	SHA,FR,SST,SPL	C,Fi	F,M,F,RY[7]
	40–95	Bt	A,S	-	5YR 2.5/2	C	WE,FI,AB	FR,ST,PL	M,Fi	V,M,F,YE[7]
	95–150	E	A,S	-	10YR 4/4	S	SG	LO,NST,NPL	M,Fi	-
	150–190	2Bth1	C,S	-	7.5YR 2.5/3	C	WE,FI,AB	FR,ST,SPL	M,Fi	M,F,F,YE[7]
	190–200*	2Bts2	-	-	5YR 3/4	C	WE,ME,AB	FR,ST,PL	C,Fi	M,F,F,YE[7]

P* = Pedon

[1] A=Abrupt; C= Clear; G= Gradual; S= Smooth

[2] C= Clay; CL= Clay loam; SiCL= Silt clay loam; S= Sand

[3] WE=Weak; MO=Moderate; FI=Fine; ME=Medium; AB= Angular blocky; SB=Sub-angular blocky; GR= Granular; SG= Single grain

[4] LO=Loose; SHA=Slightly hard; HA=Hard; FR=Friable; NST=Non sticky; SST=Slightly sticky; ST=Sticky; NPL=Non plastic; SPL=Slightly plastic; PL=Plastic

[5] V=Very few; F=Few; C=Common; M=Many; Fi=Fine; Me=Medium

[6] F,F,SF,P=Few, Faint, Shiny faces, Pedfaces; F,F,C,P=Few, Faint, Clay, Pedfaces; C,F,C,P=Common, Faint,Clay, Pedfaces

[7] F,M,F,RY=Few, Medium, Faint, Reddish yellow; V,M,F,YE=Very few, Medium, faint, Yellow; M,F,F,YE=Many, Fine, Faint, Yellow mottles.

Table 3. *Particle-size distribution of the soils*

Pedon	**Depth (cm)**	**Particle-size distribution (%)**			**Textural class[1]**	**Silt/clay**
		Sand	Silt	Clay		
1.	0–50	28	40	32	CL	1.25
	50–113	18	16	66	C	0.24
	113–220	12	8	80	C	0.10
	220–300$^+$	22	14	64	C	0.22
2.	0–20	40	32	28	CL	1.14
	20–47	18	22	60	C	0.37
	47–86	18	16	66	C	0.24
	86–200$^+$	10	12	78	C	0.15
3.	0–25	27	44	29	CL	2.00
	25–63	26	30	44	C	0.68
	63–118	14	22	64	C	0.34
	118–200$^+$	10	10	80	C	0.12
4.	0–15	30	42	28	CL	1.50
	15–58	28	40	32	CL	1.25
	58–100	14	20	66	C	0.30
	100–200$^+$	10	8	82	C	0.10
5.	0–20	30	36	34	CL	1.06
	20–52	32	32	36	CL	1.12
	52–70	26	32	42	C	0.76
	70–105	28	30	42	C	0.71
	105–200$^+$	14	33	53	C	0.65
6.	0–40	20	36	44	C	0.82
	40–95	26	32	42	C	0.86
	95–150	32	54	14	SiL	3.86
	150–190	26	26	48	C	0.54
	190–300$^+$	36	20	44	C	0.45

[1]: C = Clay; CL = Clay loam; SiL = Silt loam

The presence of an appreciable amount of the silt fraction in the surface soils could increase the water-absorbing ability of the respective soils, and facilitate a longer period of soil-water retention for plant utilisation.

Chemical properties of soils

The soil pH values within the profiles ranged from slightly to moderately acidic, and the pH values of Pedons 1–3 varied widely between the surface and subsurface layers (Table 4). The wide variation in pH values in these pedons might be due to difference in landuse, existing micro-climate and associated chemical environment. The pH level was slightly higher under the grassland than in the cultivated fields. Previous reports have also indicated that soil reaction can be influenced by various anthropogenic and natural activities (Rowell, 1994; Miller & Donahue, 1995; Brady & Weil, 2002). Relatively lower pH values in the pedons of the cultivated fields, as compared to those under grassland, might be due to depletion of basic cations in the crop harvest, and leaching. Gebeyaw (2007) also found lower pH values in cultivated land as compared to grassland, and attributed this to a high rate of organic matter oxidation, which produces organic acids and provides H-ions to the soil solution, and thereby reduces soil pH values.

The exchangeable cations in all the soils were in the order of Mg > Ca > K > Na throughout the profile, except for Pedon 6, where Ca dominated over Mg in the first two surface horizons (Table 4). This virtually indicates the dominance of Mg-bearing minerals in the weathering environment, the soil's being at relatively older stage of development, or both. Along the toposequence, the maximum value of exchangeable Mg (20.9 $\mathrm{cmol_c\ kg^{-1}}$) in the surface layer of Pedon 1 reconfirms the occurrence of Mg-rich source material. The Ca and Mg contents were above their critical limits for agricultural land; hence deficiencies of these elements would not be expected in the soils. The ratio of Ca:Mg was, however, very low, indicating that Mg could interfere with the uptake of Ca (Havlin *et al.,* 1999). On the other hand, the exchangeable K content was below the critical level of 0.38 $\mathrm{cmol_c\ kg^{-1}}$ (Landon, 1991) in two of the middle-slope topographic positions and in the depression pedons. In line with the present finding, Wondwosen (2008) also reported that K is a potentially limiting nutrient for supporting good crop growth in Alfisols of the neighboring district.

The cation exchange capacity (CEC) of the soils across the surface and subsurface layers varied between 21.3 $\mathrm{cmol_c\ kg^{-1}}$ (the surface layer of Pedon 6) and 44 $\mathrm{cmol_c\ kg^{-1}}$ (the subsurface 70–105 cm depth of Pedon 5), which could be rated as medium to high (Landon, 1991). The soils of the topographic high showed relatively higher CEC in the two surface horizons as compared to those on middle slopes, whereas that of the alluvial soil was the lowest (Table 4). The magnitude of total exchangeable basic cations followed the same trend. This was in contrast to the normal principle of basic cations' distribution. However, the data suggest that the immediate weathering products on the topographic high would have been of basic nature, as observed in basaltic soils (Heluf & Mishra, 2005). On further transformation, the exchange sites might have been occupied by other cations such as H and Al in the weathering environment. The dominant clay mineral in basaltic soils is smectite or inter-stratified minerals, including corrensite and attapulgite (palygorskite). The relatively low CEC in some of the soil profiles could be attributed to the formation of interstratified clay minerals. The base saturation varied widely, and was found to be lowest under the upper slope positions with high slope gradients.

The organic C content of the soils was low (Landon, 1991), and consistently decreased with depth, as compared to the subsoil horizons in the respective profiles. A similar trend was noted for the distribution of total nitrogen (N_{tot}; Table 5), which was also in the low to medium range (Havlin *et al.,* 1999). Organic C and N_{tot} contents were not influenced by landuse systems, possibly due to the complete removal of crop residues, and continuous heavy grazing in the case of grasslands. The C:N ratio was optimal, indicating the mineralization stage of soils and the availability of N to plants. The low content of organic C and N_{tot} could be attributed to the effects of intensive cultivation, which aggravated the oxidation of organic C. Previous findings also revealed that cultivation of land results in the reduction of organic C and N_{tot} (Saikh *et al.,* 1998; Wakene & Heluf, 2003).

The amount of available P was higher in the surface layers as compared to the subsoils in all but Pedon 6 (Table 5). However, the available P content in all the soils was very low to low (Havlin *et al.,* 1999) except in the surface layer of Pedon 1, indicating that P availability is the most limiting factor for crop production. The low availability of P might be due to the inherent P deficiency of the soils and the fixation of P with Fe and Al, as the soils are acidic in reaction. Previous reports (Kelsa *et al.,* 1998; Mulugeta Demis, 2006; Alemayehu, 2007; Tigist, 2007) have con-

Table 4. *Chemical properties of the soils*

Pedon	**Depth (cm)**	**pH-H_2O (1:2.5)**	**Exchangeable cations and CEC(cmol$_c$ kg^{-1})**						**Base Saturation (%)**
			Na	K	Ca	Mg	TEB	CEC	
1.	0–50	6.1	0.19	0.80	11.13	20.90	33.0	40.4	82
	50–113	6.4	0.25	1.55	4.64	26.2	32.6	40.6	80
	113–220	5.7	0.21	1.24	2.59	8.15	12.2	34.8	35
	220–300$^+$	5.5	0.19	0.75	1.90	3.70	6.53	32.0	20
2.	0–20	5.7	0.15	0.34	7.19	10.1	17.7	39.4	45
	20–47	4.7	0.14	0.31	6.89	9.0	16.3	37.0	44
	47–86	4.8	0.18	0.39	4.68	9.5	14.8	36.0	41
	86–200$^+$	4.5	0.15	0.51	3.13	12.1	15.9	35.0	45
3.	0–25	5.3	0.16	0.69	4.14	6.7	13.7	38.0	36
	25–63	4.7	0.18	0.43	2.74	6.1	9.4	37.4	25
	63–118	4.5	0.28	0.52	2.49	5.5	8.8	36.4	24
	118–200$^+$	6.0	0.28	0.45	2.09	5.0	7.8	33.4	23
4.	0–15	5.4	0.16	0.31	8.03	13.7	22.2	37.0	60
	15–58	5.8	0.26	0.29	9.13	24.0	33.7	39.0	86
	58–100	5.7	0.22	0.43	4.34	18.2	23.2	36.8	63
	100–200$^+$	5.3	0.25	0.54	5.19	20.1	26.0	39.4	66
5.	0–20	5.4	0.19	0.42	5.29	11.9	17.8	35.4	50
	20–52	5.3	0.14	0.32	5.24	12.3	18.0	36.0	50
	52–70	5.6	0.15	0.32	6.74	21.6	28.8	38.0	76
	70–105	5.7	0.18	0.42	5.84	24.1	30.5	44.0	69
	105–200$^+$	5.8	0.20	0.64	4.69	26.9	32.4	39.0	83
6.	0–40	6.1	0.17	0.24	6.00	3.7	10.1	21.3	47
	40–95	6.2	0.17	0.39	8.41	4.2	13.2	32.0	41
	95–150	6.0	0.15	0.31	8.03	10.5	19.0	35.0	54
	150–190	6.3	0.24	0.27	9.13	11.5	20.7	37.0	56
	190–300$^+$	6.3	0.21	0.43	8.34	12.2	21.2	36.8	58

TEB = Total exchangeable bases

firmed that the available P content of most soils in the region is low, and that P fertiliser application is required for optimum crop production.

Conclusions

The differences in landuse systems, grassland and cultivated, resulted in varying physico-chemical properties of the soils. The variations in soil characteristics observed in the studied four (Pedons 2–5) of the six pedons were due to differences in slope and soil management. Soil Pedon 5 was located on mid-slope, but at the lower side of a terrace, where soil materials removed from upslopes were continuously deposited. The subsequent accumulation of materials resulted in the development of a thick A horizon, indicating the role of soil conservation practices in soil development and characteristics. The soils are low in organic C, N_{tot} and available P content, hence integrated plant-nutrient management, together with soil conservation practices, should be employed to ensure sustainable crop production at the site.

Table 5. *Organic carbon, total nitrogen and available phosphorus of the soils*

Pedon	Depth (cm)	Organic carbon (%)	Total nitrogen (%)	Carbon : nitrogen ratio	Available P (mg kg^{-1})
1.	0–50	1.68	0.175	10	7.80
	50–113	0.65	0.080	8	2.20
	113–220	0.55	0.070	8	1.00
	$220–300^+$	0.39	0.042	9	1.40
2.	0–20	1.56	0.175	9	3.20
	20–47	1.15	0.133	9	0.80
	47–86	0.94	0.119	8	1.00
	$86–200^+$	0.64	0.084	8	1.00
3.	0–25	1.42	0.133	11	2.40
	25–63	1.12	0.126	9	0.40
	63–118	0.77	0.106	7	0.60
	$118–200^+$	0.58	0.084	7	0.80
4.	0–15	1.59	0.175	9	4.60
	15–58	1.59	0.161	10	1.40
	58–100	0.53	0.042	13	1.80
	$100–200^+$	0.47	0.098	5	1.40
5.	0–20	1.47	0.154	10	3.00
	20–52	1.38	0.133	10	2.20
	52–70	1.32	0.119	11	0.60
	70–105	1.14	0.119	10	0.80
	$105–200^+$	0.63	0.091	7	0.60
6.	0–40	1.27	0.147	9	2.20
	40–95	1.18	0.110	11	1.20
	95–150	0.42	0.042	10	1.00
	150–190	0.74	0.091	8	2.40
	$190–300^+$	0.76	0.063	12	3.80

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